A COMPARISON OF TWO VISUAL SURVEY TECHNIQUES FOR FISH POPULATIONS

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ABSTRACT

Two visual census techniques for describing and quantifying fish communities, the "Brock method" and the "Jones and Thompson method," were compared in terms of replicability, observer bias, minimal number of replicate surveys required to adequately represent the species composition of a specific fish community under study, daily variations in the data, and sensitivity to distinctions between fish communities. In addition, the degree of correlation between surveys of the two methods was calculated. More than 250 surveys of each method were conducted at five sites off Molokai, Hawaii and at Hanauma Bay off Oahu, Hawaii.

Molokai residents have voiced concern regarding the increasing and conflicting uses of marine resources. Since coastal zone management decisions made by government agencies are based in part on marine resource assessments, baseline data on fish, algae, and coral populations were acquired at the five previously unstudied Molokai sites.

Spearman rank correlation coefficients were calculated between single surveys of each method and between the averages of four replicate surveys of each method. These analyses were performed on the abundance ranking of each species recorded by the two survey techniques. When four surveys were averaged, an increase in the correlation within methods was reflected in an increase in the correlation between methods. This direct relationship suggested that replicate surveys of each method approached accuracy.

The correlation coefficients for Jones and Thompson surveys were significantly lower than those for Brock surveys, indicating that the results of Jones and Thompson surveys were more variable. A significant difference between data collected by different Jones and Thompson observers suggested that observer bias was responsible in part for the lower replicability.

The mean number of species recorded per survey and the total number of species recorded per site were approximately equal for the two methods. Consequently, the minimal number of replicate surveys required to adequately represent the species composition of the community under study would be approximately equal for the two methods. There were no statistically significant daily variations in the data. The two methods were equally sensitive to distinctions between fish communities.

Both the Brock method and the Jones and Thompson method are valid visual survey techniques. When an area is under intensive study and replicable surveys are essential, the Brock method should be used. In cases where the length of each individual fish must be noted to obtain biomass approximations, the Brock method must be used. When available field time is minimal and the main objective is to characterize fish communities so that sites can be distinguished on that basis, the Jones and Thompson method is more cost-effective. The Jones and Thompson method would also be preferred when bottom time is a critically limiting factor or when conditions of strong current, heavy surge, or extreme vertical relief prohibit the setting of a transect line.

I. INTRODUCTION

The 1,207 km of coastline surrounding the Hawaiian Islands are an invaluable local and national resource in terms of commercial and subsistence fisheries, aquaculture, transportation, waste disposal, recreation, and tourism. As the resident population and the number of visitors rise steadily, increasing and often conflicting demands are made on marine resources. Consideration of the impact of these demands requires a knowledge of baseline conditions in the nearshore environment. Coastal zone management decisions made by government agencies are based in part on marine resource assessments, including censuses of fish, algae, and coral populations.

Numerous survey techniques have been described (Russell, Talbot, Anderson, & Goldman, 1978) but comparisons between these techniques are lacking and information on relative selectivity or bias is not available. To assure a sound data base, comparative studies of survey methodologies are needed.

Two frequently employed visual survey techniques for fish populations, the "Brock method" (Brock, 1954) and the "Jones and Thompson method" (Jones & Thompson, 1978) were compared in terms of replicability, observer bias, minimal number of replicate surveys required to adequately represent the species composition of the specific fish community under study, daily variations in the data, and sensitivity to distinctions between fish communities. In addition, the degree of correlation between surveys of the two methods was calculated. These comparisons were made using more than 500 surveys conducted in coral, boulder, basalt pavement, and limestone pavement habitats.

In contrast to the island of Oahu [land area of 1,535 km^2 (Armstrong, 1973), estimated 1978 population of 719,600 (State of Hawaii Department of Planning and Economic Development, 1979)], the island of Molokai (676 km^2, population of 6,200) is in the early stages of urban development (Figure 1). The rural lifestyle of the residents traditionally involves a cultural communion with the ocean which includes a partial food subsistence. The residents have recently voiced concern regarding the increasing uses of marine resources, including commercial and local fishing, establishment of conservation and management districts, and erosion resulting from shoreline development and agriculture.

In 1977, Fred D. Bicoy, Coordinator of the Molokai Community Action Council, met with other community leaders to identify the five survey areas of highest priority: Palaau, Moanui, Halawa Bay, Keawanui, and Ilio Point (Figure 2). Residents are concerned about the extent of commercial fishing which is done in the shallow waters of Palaau mudflats. At Moanui, residents have suggested that the area inside and/or outside the reef be designated a management or conservation district. Halawa Valley is an area of proposed resort development. Molokai residents are interested in the effects which the limited public access to Ilio Point and Keawanui has had on fish populations at these sites. Ilio Point is accessible only to four-wheel-drive vehicles with permission from Molokai Ranch. Keawanui is accessible only via hiking trails and boats. During the winter months, sea conditions usually prevent boat access to Keawanui.

Replicate surveys of the Brock method and the Jones and Thompson method conducted at the five Molokai sites not only provided data for a comparison of the methods but fulfilled a need for quantitative assessments of the fish, algae, and coral populations at the sites. Prior to the Molokai fieldwork, data for the method comparison were acquired on Oahu at a site in Hanauma Bay.

II. FIELD METHODS

A. Participant Preparation

Accurate and rapid identification of organisms in the field is essential to visual survey work. With assistance from faculty and staff at the University of Hawaii, an intensive training program was designed to include fish, algae, and coral identification courses and survey methodology training sessions. S. L. Sanderson and A. C. Solonsky completed such training in March 1978 and designed and directed the training program for the other eight project participants from October 1978 through May 1979.

A Hawaiian Reef Fish Identification Course was one aspect of this program and was offered through the Waikiki Aquarium. It covered the taxonomy and ecology of 175 species from 45 families. The training program also included a Hawaiian Algae Identification Course which was similarly offered through the Waikiki Aquarium. This course encompassed 110 species from 4 phyla. The training in coral identification involved the study of 35 coral species from 10 families. References, 35 mm slides, field trips to reefs, and a visit to one of the more complete coral collections in the state served as aids.

From January to May 1979, fish survey methodology training sessions were held at Hanauma Bay, a marine conservation district with considerable diversity and abundance of fish. All participants were certified in the use of SCUBA, and all surveys were conducted with SCUBA to permit surveyors to swim directly above the substratum.

B. Fish Surveys

Modifications of the Brock method and the Jones and Thompson method were used during daylight hours. Both methods utilized 50 meters of a non-floating synthetic line. Data were recorded by species name on pre-printed underwater paper attached to clipboards. Transcription of data from underwater paper to computer-coded sheets took place immediately following completion of the surveys at each site.

1. Brock Surveys

In the Brock surveys, two people swam abreast, one on each side of the line, and recorded each individual fish seen within 2.5 m of their side of the line and 2 m above the substratum. The observers began the survey simultaneously at one end of the line and did not halt until the survey was completed at the other end of the line. Fish which crossed the line were recorded only on the side where they originated. Depth, visibility, and the time required to complete the survey were recorded. During transcription, the two observers combined their data to arrive at the total number of individuals of each species seen in the area 5 m across the line.

2. Jones and Thompson Surveys

In the Jones and Thompson surveys, one person (the observer) recorded species seen in the area 5 m across the line and 2 m above the substratum while the other person (the time monitor) followed the observer and gave a tactile signal at the end of each of twelve one-minute intervals. During the first interval, a value of twelve was assigned to each species seen. During the second interval, a value of eleven was given to previously unseen species. The observer continued to assign successively lower values to new species seen in successive time intervals until a cumulative list with species labeled from twelve to one was obtained.

This method is based on the assumption that the species which are most abundant will be encountered within the earliest time intervals. The observer swam slowly enough to record species in the order in which they were encountered. When the end of the line was reached before the twelve minutes were over, the observer swam back along the line and continued to record species for the remaining time intervals.

The Jones and Thompson method is appropriate for use only at sites where the survey can be completed over a uniform substratum type. Variations in the substrata, and therefore in the habitat, which occur over the course of observation may cause inaccurate abundance rankings. For example, if the observer swims over coral rubble during the first half of the survey and boulders during the second half, those species which frequent boulder habitats will be given a low abundance ranking regardless of their actual abundance.

3. Modifications

For purposes of comparison, both the Brock and the Jones and Thompson methods were modified. The originally described Jones and Thompson method did not utilize a transect line. The observer was allowed to swim randomly within the physical confines of the specific reef under study. However, we conducted surveys of both methods over the same lines. To ensure that the transect line could be set over a consistent substratum, a 50 m line was used rather than Brock's 500 yd line. Nolan and Taylor (in press) concluded that the optimal compromise between effort and accuracy in their use of the Brock method on shallow coral reefs was achieved with a 50 m transect.

Our preliminary surveys on Hawaiian reefs indicated that the majority of species present were seen within the first ten minutes of observation. Therefore, for the Jones and Thompson surveys, one-minute intervals were used in place of the original ten-minute intervals. Intervals of one minute duration enabled the observer to record an abundance ranking.

4. Hanauma Bay Fieldwork

Throughout the eleven days of fieldwork during June 1979 at Hanauma Bay on Oahu, two pairs of parallel 50 m lines were set end to end over a uniform substratum. The lines in each pair, designated Lines One and Two and Lines Three and Four, were approximately 7 m apart (Figure 3). On all the days of surveying, the beginning and the end of each line were attached to the same coralheads. Surveys were begun approximately ten minutes after the lines had been set. Four two-person teams--A, B, C, and D--remained constant throughout the Hanauma fieldwork, as did the roles of observer and time monitor for the Jones and Thompson surveys.

On a given day, Teams A and B surveyed on one pair of lines while Teams C and D surveyed on the other pair of lines. The teams alternated between surveying Lines One and Two and surveying Lines Three and Four. Each team performed both the Brock and the Jones and Thompson methods on each of the two lines and repeated this procedure for a total of eight surveys per team per day (Table 1).

5. Molokai Fieldwork

Depth, water clarity, and amount of suitable (non-sand) substrata were limiting factors in the selection of specific survey sites. To facilitate the required repetitive diving, dives were made no deeper than 60 feet. The use of visual census methods as described in this report necessitated a minimum visibility of 2.5 m. Due to limited visibility, it was not possible to survey the waters directly over the Palaau mudflats or the nearshore waters in Halawa Bay.

Sand substrata are relatively barren of algae and coral cover. Fish species which are characteristic of sand habitats are free-ranging and difficult to census. Consequently, surveys were not conducted over sand substrata.

Surveys on Molokai were conducted in basically the same manner as were the Hanauma surveys. The charter of the R/V Machias from July 1 through July 18, 1979 permitted the collection of baseline data at sites which are difficult to survey with a shore-based operation due to rough sea conditions and/or limited overland access. Sites with suitable depth, water clarity, and substrata were selected from an inflatable boat. Coordinates were recorded based on radar observation from R/V Machias. At each site, one pair of parallel 50 m lines was set approximately 7 m apart and surveys were begun immediately. Two two-person teams and one safety diver remained constant throughout the Molokai fieldwork, as did the roles of observer and time monitor for the Jones and Thompson surveys. Each observer conducted both one Brock and one Jones and Thompson survey on each of the two lines for a total of four surveys per site. Schools or unusual species occurring more than 2.5 m from the line were noted but were not included in the data analyses.

Molokai surveys were conducted at a total of 33 sites from 5 areas--Palaau, Moanui, Halawa Bay, Keawanui, and Ilio Point (see Appendix A for maps). A coral, an algae, and a fish dendrogram were plotted to determine the similarity patterns among these sites. The coral dendrogram and the algae dendrogram were derived from the raw data acquired during the 33 coral and 33 algae surveys. These raw data consisted of the species observed and the number of quadrat points which each species occupied. The fish dendrogram was derived from data obtained by averaging the four Brock surveys conducted at each site. Brock surveys were averaged by summing the number of fish recorded for each species and dividing the sum by four.

The dendrograms are discussed in Appendix B. In general, the sites clustered according to the area in which they were located. With the exception of Keawanui, each Molokai area can be considered as a habitat distinct from the other Molokai areas studied.

C. Algae and Coral Surveys

The algae and coral surveys were done in conjunction with the fish surveys at each Molokai site to allow for a comparison of algae, coral, and fish populations. Upon completion of the fish surveys, algae and coral surveys were conducted by two observer pairs and one safety diver on one of the two 50 m lines set over a uniform substratum type by the fish surveyors.

A modified point-quadrat method was used (Goodall, 1952). The 0.5 m by 0.5 m quadrat (0.25 m^2) consisted of a square of lead-weighted PVC tubing and equidistant points formed by intersecting monofilament lines. Twenty-five equidistant points were used for the algae surveys; nine for the coral. Most coral colonies were larger than the algae, necessitating the wider spacing of points in the coral quadrat.

The 50 m line was numbered at 1 m intervals. Prior to each algae and coral survey, random numbers between 0 and 50 were obtained from a random number table. During the algae surveys, the quadrat was placed directly on the substratum at each of four random numbers along the line and the alga occurring under each of the twenty-five points was recorded by species on pre-printed underwater paper attached to clipboards. A total of 1.0 m^2 (four quadrats) was surveyed per site.

During the coral surveys, the quadrat was placed at each of ten random numbers along the line, and the coral species occurring under each of the nine equidistant points was recorded on underwater paper. To obtain an adequate number of points, 2.5 m^2 (ten quadrats) were surveyed per site.

In the absence of algae and/or coral, the type of substratum under the points was recorded (i.e. sand, coral rubble, boulder, silt, limestone pavement, or basalt pavement). The general characteristics of each site, including substratum type, were noted and photographed. Unidentified species were collected for laboratory identification. Algae were preserved in 10% formalin and/or pressed on herbarium paper; corals were bleached in sodium hypochlorite solution. Transcription of data from underwater paper to computer-coded sheets took place immediately after each survey.

III. STATISTICAL METHODS

To determine the correlation between pairs of Brock surveys, between pairs of Jones and Thompson surveys, and between pairs consisting of one Brock and one Jones and Thompson survey, Spearman rank correlation coefficients were calculated from the raw data. For each survey, the species seen were ranked as explained below. The differences between the rank assigned to each species in one survey and the rank assigned to each of the same species in the other survey were then calculated. The correlation coefficient (r_s) between the two surveys was computed using the equation

$$r_s = 1 - \frac{6\Sigma d^2}{n^3 - n}$$

where d equals the difference between the ranks for each species and n equals the number of differences calculated.

For each Brock survey, the species seen were ranked according to the number of individual fish of that species recorded by the observers. The rank of 1 was assigned to the most abundant species, the rank of 2 to the second most abundant species, etc. If two or more species were observed to be equally abundant, their ranks were averaged. For example, if an equal number of individual fish were recorded for the species with ranks 3 and 4, those species would receive a tied rank of 3.5.

For each Jones and Thompson survey, the species seen were ranked according to the time interval number recorded by the observer. Tied ranks were frequently assigned to species recorded using the Jones and Thompson method. For example, if three species were encountered within the first time interval and, therefore, had a time interval number of twelve, those species were assigned a tied rank of 2. For surveys of either method, when a species was observed during one survey but not during the other, that species was assigned the highest rank in the survey during which it was not observed. The use of Spearman rank correlation coefficients permitted the numbers of individual fish obtained from Brock surveys to be ranked independently of the time interval numbers obtained from Jones and Thompson surveys.

The possible values for this correlation coefficient range from -1.0 to +1.0, with -1.0 representing an inverse relationship between the species abundances recorded during the two surveys, 0 representing the lack of a relationship, and +1.0 representing a direct relationship. A table of critical values for Spearman rank correlation coefficients provided p values for the correlation coefficients computed between surveys. In the calculation of these correlation coefficients, ties frequently occurred in the species ranks for surveys of both methods. Although a formula has been described (Lehmann, 1972) which takes into account the occurrence of such ties by providing a means of calculating the consequent lower statistical significance of the correlation coefficients, the use of this formula was not deemed to be of sufficient importance to this study. The p values for the correlation coefficients reported throughout this study are consistently lower than they would have been if the tied ranks had been taken into account.

We plotted frequency distributions to illustrate the frequency of correlation coefficients which were within ranges from 0 to 1.0. Frequency distributions of correlation coefficients calculated from data collected by different observers or in different habitats were compared using Chi-square tests of independence (Sokal & Rohlf, 1969). Based on the null hypothesis of the independence of the variables (observers or habitats), expected frequencies were computed. The goodness of fit of the observed frequencies to the expected frequencies was then tested. A low level of significance indicated that the variables were independent and that there were no statistically significant differences between the frequency distributions under comparison. When a high level of significance was obtained, the null hypothesis was rejected.

IV. RESULTS AND DISCUSSION

A. Correlation Between Methods

Data collected by two observer teams on a total of fifty lines set at five areas off Molokai over a period of fifteen days were used to test the agreement between the Brock and the Jones and Thompson methods. Spearman rank correlation coefficients were calculated between a single Brock survey and a single Jones and Thompson survey, both of which were conducted by one observer team on one line approximately fifteen minutes apart. Brock surveys were usually completed within six to ten minutes while Jones and Thompson surveys were conducted for twelve one-minute intervals. Prior to calculation of the correlation coefficients, the data obtained from each Jones and Thompson survey were computer-edited to include only those species which were recorded within the number of minutes necessary to complete the corresponding Brock survey. Calculations were consequently not based on an arbitrary number of Jones and Thompson time intervals.

Low correlation coefficients between and within methods were frequently due in part to fish belonging to particular families. Species which are generally not territorial or which have extensive home ranges (i.e. members of the families Carangidae, Kyphosidae, and Scaridae) tended to swim sporadically through the survey areas so that their recorded abundance may not have been representative of their actual abundance. Nocturnal predators (i.e. members of the families Muraenidae and Holocentridae) and other secretive species (i.e. members of the families Gobiidae and Blenniidae) are difficult to survey accurately and were therefore also encountered less consistently.

Figure 4 is a frequency histogram for the ninety-nine correlation coefficients calculated from data collected by two observer teams at five areas off Molokai. Forty-five percent of the correlation coefficients were within the range of 0.41 to 0.60. Sixty-six percent were statistically significant ($p \leq .01$). In a Chi-square test of independence, no statistically significant differences ($p \leq .975$) were found between the frequency distributions for the two observer teams, indicating that the degree of correlation between methods did not change with different observers.

From sixteen to forty-three correlation coefficients were calculated between methods for each of four Molokai areas. Due to time constraints in the field, data were available for the calculation of only four correlation coefficients for Keawanui. As discussed on page 10, each Molokai area can be considered as a habitat distinct from the other Molokai areas studied. Using a Chi-square test of independence, no statistically significant differences ($p \leq .9$) were found in the correlation coefficients from the five areas, indicating that the correlation between methods did not vary significantly with habitat.

Data collected by four observer teams on four lines at Hanauma Bay over a period of eleven days were used in the same manner to determine the correlation between methods. The solid curve in Figure 5 is the frequency distribution for the 160 correlation coefficients calculated from these data. Sixty-nine percent of these correlation coefficients were statistically significant ($p \leq .05$). These data are similar to the data presented in Figure 4.

Spearman rank correlation coefficients were also calculated between the average of four Brock surveys and the average of four Jones and Thompson surveys, all of which were conducted by one observer team on one pair of lines at Hanauma Bay during one day. Surveys of one method were begun approximately thirty to forty-five minutes apart and surveys alternated between methods according to the schedule in Table 1. Brock surveys were averaged by summing the number of fish recorded for each species and dividing the sum by four. A similar procedure, summing the time interval number for each species, was used to average Jones and Thompson surveys. Due to the mobility of fishes and to the specific field conditions during the survey, observations which are not representative of the site under study may be recorded. By putting such atypical observations into proper perspective, the averaging procedure increased the correlation between methods. The broken curve in Figure 5 is the frequency distribution for the thirty-six correlation coefficients calculated between the averages of Brock and of Jones and Thompson surveys. All of these correlation coefficients were statistically significant ($p \leq .01$).

B. Correlation Within Methods

The degree of correlation between repeated surveys of one method is a measure of the replicability of surveys of that method. Data collected by four observer teams on four lines at Hanauma Bay over a period of eleven days were used to determine the replicability of Brock and of Jones and Thompson surveys. Spearman rank correlation coefficients were calculated between pairs of Brock surveys and between pairs of Jones and Thompson surveys. The surveys in each pair were conducted by one observer team on one line and were begun approximately one hour apart.

In Figure 6, each bar represents the correlation coefficients obtained between two Brock surveys and between two Jones and Thompson surveys, all of which were conducted by one observer team on one line during a single day. The correlation coefficients for Brock surveys were consistently higher than those for Jones and Thompson surveys (Wilcoxon signed rank test, $p \leq .0005$), indicating that the Brock surveys were more replicable. For the Brock surveys, seventy percent of the correlation coefficients were greater than 0.50 while for the Jones and Thompson surveys only eleven percent were greater (solid curves in Figure 7). Eighty-eight percent of the correlation coefficients between Brock surveys were statistically significant ($p \leq .01$). In contrast, $p \leq .01$ for only thirty-three percent of the Jones and Thompson surveys.

Similar results were obtained from data collected by two observer teams on a total of fifty lines set at five areas off Molokai. Using a Chi-square test of independence, no statistically significant differences ($p \leq .5$) were found between the frequency distributions for the two observer teams, indicating that the degree of correlation within methods did not change with different observers.

Between eight and twenty-one correlation coefficients were calculated for each method at each of four Molokai areas. Two correlation coefficients were calculated for each method at Keawanui. In a Chi-square test of independence, no statistically significant differences ($p \leq .9$) were found in the coefficients from the five areas, indicating that the replicability of the methods did not vary significantly with habitat. Larger sample sizes are needed for more definitive results.

The Hanauma Bay data were used to calculate correlation coefficients between the average of four Brock surveys conducted by one observer team on one pair of lines during one day and the average of four Brock surveys conducted by the same observer team on the same pair of lines during a different day. Correlation coefficients were also calculated between the averages of Jones and Thompson surveys. Data from different days were used because it was not feasible to conduct eight Brock and eight Jones and Thompson surveys on the same pair of lines during the same day.

In Figure 7, the broken curves are frequency distributions for the twenty-four correlation coefficients calculated between averaged surveys of each method. All of these correlation coefficients were statistically significant ($p \leq .01$). The solid curves are frequency distributions for the thirty-six correlation coefficients calculated between pairs of surveys of each method. The surveys in each pair were conducted by one observer team on one pair of lines during one day. The frequency distributions for the averaged surveys plotted to the right of the distributions for the single surveys ($p \leq .005$), indicating that the correlation within methods increased significantly as a result of the averaging procedure.

C. Number of Species Observed

Results of correlated analyses of variance showed no statistically significant differences ($p \leq .1$) at each of four areas on Molokai and at Hanauma Bay between the mean number of species recorded per Brock survey and the mean number recorded per Jones and Thompson survey. At only one Molokai area, Halawa Bay, was there a significant difference ($p \leq .05$) between the average of 29.50 species observed per Brock survey and the average of 27.75 species observed per Jones and Thompson survey. This difference may be due to the boulders as large as 2.5 m in diameter which comprised the substratum at the Halawa survey sites and which tended to create more of a blind spot for the single Jones and Thompson observer than for the team of two Brock observers.

Results of an additional correlated analysis of variance showed no statistically significant differences ($p \leq .5$) at each of the five Molokai areas and at Hanauma Bay between the total number of species recorded during Brock surveys and the total number recorded during Jones and Thompson surveys. To avoid basing the above analyses on an arbitrary number of Jones and Thompson time intervals, the data obtained from each Jones and Thompson survey were computer-edited to include only those species which were recorded within the number of minutes necessary to complete the corresponding Brock survey.

D. Minimal Number of Replicate Surveys

In vegetation ecology when sampling for recurring plant assemblages, it is common practice to determine the minimal sample area of a community. Minimal area is defined as "the smallest area on which the species composition of the community in question is adequately represented" (Mueller-Dombois & Ellenberg, 1974, p. 47). For surveys of consistent size, this smallest area can be equated with the smallest number of replicate surveys required to adequately represent the species composition of the community under study.

Minimal area is determined from a cumulative species-area curve on which survey areas of increasing size are plotted on the abscissa against number of species observed. Similarly, the minimal number of replicate surveys can be determined from a cumulative species-replicate curve on which an increasing number of replicates is plotted against number of species observed (Figure 8). To identify the minimal number of replicates, the slope of the species-replicate curve must eventually approach zero. Near the point where the species-replicate curve becomes almost horizontal, a sufficient number of replicates will have been conducted to adequately represent species composition. Each additional replicate may yield one or two previously unrecorded species but these few species will compose only a small fraction of the total number observed in the community.

Engen (1976) reported a formula for the estimation of points on the species-area curve. Using Engen's approach, species-replicate curves were plotted for Brock and for Jones and Thompson surveys at each of the five Molokai areas. Prior to the estimation of points, the data obtained from each Jones and Thompson survey were edited to include only those species which were recorded within the number of minutes necessary to complete the corresponding Brock survey.

Although the five Molokai areas can be considered as five distinct habitats, the substratum at each area was not homogeneous and surveys were conducted in different subhabitats. Consequently, several fish communities were surveyed at each area. Since the surveys were not actual replicates, the species-replicate curves for each area did not reach a plateau. Additional surveys conducted in different subhabitats yielded observations of additional species, resulting in a steep slope for the curve. When different subhabitats are studied and a species-replicate curve is plotted for the overall habitat, the curve will reach a plateau only if a very large number of surveys are conducted.

Jones and Thompson used the P_k statistic of Gaufin, Harris, and Walter (1956) "to determine the number of replicate 50-min counts considered necessary to account for 90% or more of the ubiquitous species in a community" (Jones & Thompson, 1978, p. 163). This statistic required that Jones and Thompson designate _a priori_ the number of surveys which would be adequate to account for 100% of the species in the communities under study. Since this assumption would not have been realistic in our study, we used Engen's approach rather than the Gaufin statistic.

The species-replicate curves for the two methods at each of the Molokai areas were similar. This result is consistent with the fact that there were generally no significant differences between the mean number of species recorded per Brock survey and the mean number recorded per Jones and Thompson survey or between the total number of species recorded at each area during Brock surveys and the total number recorded during Jones and Thompson surveys (page 19). In each area, previously unseen species were observed at approximately equal rates during surveys of both methods. Therefore, it can be predicted that the minimal number of replicate surveys required to adequately represent the species composition of the community under study would not differ significantly between the two methods.

The Gaufin statistic was developed as a criterion for evaluating the efficiency of different sampling devices and does not require assumptions "concerning the randomness of sampling or the distribution or relative abundances of the species" (Gaufin et al., 1956, p. 648). As with the Engen method, minimal number of replicates required to adequately represent species composition is not necessarily related to accuracy in determination of species abundance.

E. Observer Differences, Daily Differences

Dendrograms were employed to identify similarity patterns among surveys conducted by various observers on various days. The time interval numbers assigned to each species during Jones and Thompson surveys or the numbers of individual fish recorded for each species during Brock surveys were subjected to similarity tests (Mueller-Dombois & Bridges, 1975). The dendrograms were derived from an unweighted pair-group clustering (McCammon & Wenninger, 1970) of pairwise similarity coefficients (Bray & Curtis, 1957).

Four dendrograms were plotted to determine the extent to which the conducting of surveys by different observers and during different days was evident in the data collected. Each dendrogram was based on a total of twenty surveys of one method conducted by four observer teams during five different days on one line at Hanauma Bay. Two of the dendrograms consisted of Brock surveys and two of Jones and Thompson surveys. For each method, one dendrogram was drawn of surveys conducted on Line Two and the other dendrogram of surveys conducted on Line Four. Since all four transect lines at Hanauma Bay were located in one habitat, the dendrograms of the two lines were similar.

For all four dendrograms, the similarity values between surveys ranged from 54% to 88%, indicating that the surveys which comprised each dendrogram shared very similar properties. In addition, this relatively narrow range of similarity values demonstrated that the limited variation between the surveys in each dendrogram was relatively consistent.

In Chi-square tests of independence, the frequency of simple clusters of two surveys conducted by the same observer team irrespective of day was not statistically significant ($p \leq .5$). For both the Brock and the Jones and Thompson methods, the use of different observers on different days was generally not reflected in dendrograms of the data collected.

The Hanauma Bay data were examined further to resolve the significance of the difference between data collected by different observers using the Jones and Thompson method. Spearman rank correlation coefficients were calculated between the average of four surveys conducted by one observer on one pair of lines during one day and the average of four surveys conducted by a different observer on the same pair of lines during a different day. Data from different days were used because it was not feasible to conduct eight Brock and eight Jones and Thompson surveys on the same pair of lines during the same day.

The solid curve in Figure 9 is the frequency distribution for these correlation coefficients while the broken curve is the frequency distribution for correlation coefficients calculated in the above manner from surveys conducted by the same observer on the same pair of lines during different days. The results of a Chi-square test of independence showed that the frequency distribution of the correlation coefficients for same observers is significantly shifted to the right ($p \leq .005$) of the frequency distribution for different observers, indicating that there was a significant difference between data collected by different observers using the Jones and Thompson method.

Observer differences were not as significant in the dendrograms because the dendrograms were computed from single surveys whereas the correlation coefficients plotted in Figure 9 were calculated from averaged surveys. The observer bias became more distinguishable as a result of the averaging procedure which reduced the deviation from a central tendency. The lower replicability of Jones and Thompson surveys compared to Brock surveys (page 17) is indicative of the degree of inherent variability in data collected using the Jones and Thompson method. Due to this inherent variability, most observer bias will be indistinguishable when a limited number of Jones and Thompson surveys are conducted by different observers. When a large number of surveys are involved, observer bias will become significant.

Thompson and Schmidt (1977) used Spearman rank correlation coefficients to test the agreement between surveys conducted by different observers at the same sites. Individual species scores were summed from eight replicate fifty-minute surveys conducted by each of two observers. A correlation coefficient of 0.92 ($p \leq .001$) was calculated between the summed species scores for each observer. In contrast, the correlation coefficients which we calculated between the average of four surveys conducted by one observer and the average of four surveys conducted by a different observer (solid curve in Figure 9) ranged from 0.42 to 0.80.

Observer bias may have been more evident in our study due to our use of one-minute time intervals rather than the ten-minute intervals used by Thompson and Schmidt. In our studies on Hawaiian coral reefs, we found that the majority of fish species were recorded within the first ten minutes. The use of longer time intervals by Thompson and Schmidt may have decreased observer bias by reducing the importance of the order in which observers recorded species. The use of shorter time intervals may increase observer bias while also increasing the resolution of the method in determining relative abundances of species.

The calculations described above for Jones and Thompson surveys were repeated for Brock surveys. No statistically significant differences ($p \leq .5$) were found between the frequency distribution for surveys conducted by the same observer and the frequency distribution for surveys conducted by different observers.

F. Sensitivity to Distinctions Between Fish Communities

In the four dendrograms discussed above, each based on twenty surveys of one method (page 22), the lowest similarity values ranged from 54% to 63%. Since the surveys comprising each dendrogram were conducted on one transect line, the similarity values between surveys should ideally have been 100%. Of course, the mobility of fishes, as well as variability in field conditions on the five days and variability between the four observer teams, caused the similarity values to be less than 100%. A disparity between surveys which should ideally have 100% similarity indicates that there exists a limit of sensitivity to differences between surveys from different sites. For example, if under certain field conditions surveys of one method from one site are only 50% similar, then under those conditions the method cannot be relied upon to distinguish between different sites which are 75% similar.

The lowest similarity values of 54%-63% can be considered as the lower limit of the sensitivity of the survey methods, under the specific field conditions of this study, to changes in a fish community at a single site through time or to differences between fish communities at different sites. If fish communities at different times or different sites were less than 54% similar, surveys conducted by the four observer teams used in this study under the field conditions encountered would have provided data sufficient to detect the difference. If fish communities were more than 54% similar, distinctions between the communities may not have been accurately recorded.

In each of the five Molokai areas studied, between one and nine pairs of transect lines were set at specific sites. At each site, each observer team conducted one Brock and one Jones and Thompson survey on each of the two lines for a total of four surveys. Dendrograms were used to determine the extent to which the sites could be distinguished on the basis of these surveys.

Each of four dendrograms was comprised of thirty-four surveys of one method conducted by one observer team--two surveys at each of seventeen sites--over a period of fourteen days. In the two Brock dendrograms, the surveys from 47% of the sites clustered together as simple pairs. No similarity patterns in the form of simple pairs were found among the surveys from the other sites. In the two Jones and Thompson dendrograms, the surveys from 62% of the sites clustered as simple pairs. In a Chi-square test of independence, the difference between the number of sites identified as simple pairs for the two methods was not statistically significant ($p \leq .5$).

While distinctions could be made between only half the sites on the basis of the similarity patterns in the dendrograms, it should be noted that the dendrograms were comprised of single surveys rather than averaged surveys. As previously discussed (page 17), observations which are not representative of the site under study may be recorded during single surveys. It is expected that a greater number of sites could be distinguished using dendrograms comprised of averaged surveys.

V. SUMMARY AND CONCLUSIONS

The degree of correlation between repeated surveys of one method is a measure of the replicability of surveys of that method. However, replicability is not necessarily related to accuracy. Surveys could be replicable yet be consistently inaccurate. Can conclusions regarding accuracy be reached?

For both single surveys and averaged surveys, the degree of correlation between methods approximated the degree of correlation within methods. When four surveys were averaged, an increase in the correlation within methods was reflected in an increase in the correlation between methods (Figure 10). This direct relationship suggested that replicate surveys of each method approached accuracy.

The degree of accuracy towards which replicate surveys of the two methods converge is, of course, limited by any systematic errors which are present in both methods. For example, both methods tend to under-represent cryptic species so that the degree of accuracy approached does not include an accurate representation of such species. The use of additional survey methods with different systematic errors would aid in identifying the systematic biases present in the other methods under consideration as well as aid in defining the degree of accuracy towards which the other methods are converging. For example, the use of an ichthyocide following replications of the Brock and the Jones and Thompson methods would provide information regarding the relative accuracy of these three methods in representing cryptic species.

If replicate surveys of each method approached accuracy, it can be further inferred that the lower replicability of Jones and Thompson surveys compared to Brock surveys was due to lower accuracy of Jones and Thompson surveys. The significant difference between data collected by different observers using the Jones and Thompson method indicated that observer bias was responsible in part for the lower accuracy of Jones and Thompson surveys. The greater observer bias in Jones and Thompson surveys compared to Brock surveys may be due to the use of only one observer in the Jones and Thompson method. By combining the data collected by the two observers employed in the Brock method, the effects of observer bias may be lessened.

Prior to their participation in this study, the observers had been involved in a comprehensive training program and had acquired approximately equal experience in fish identification and visual surveying. The degree of correlation between methods or within the Brock method did not change significantly with the use of different observers. Similarly, the degree of correlation between methods or within either method did not change significantly in different habitats. The relatively constant frequency distributions of correlation coefficients suggested that there were no observer characteristics which affected the replicability of Brock surveys and no habitat characteristics which affected the replicability of surveys of either method.

The mean number of species recorded per survey and the total number of species recorded per site were approximately equal for the two methods. Consequently, the minimal number of replicate surveys required to adequately represent the species composition of the community under study would be approximately equal for the two methods. Observer bias in the Jones and Thompson method did not involve exclusion of species but rather occurred in the assigning of time interval numbers to species.

A Jones and Thompson survey can be completed in fewer than half the man-hours needed to conduct a Brock survey. As originally decribed by Jones and Thompson, it is not necessary to set a transect line and one person can serve as both observer and time monitor. Although Jones and Thompson surveys were less replicable and less accurate than Brock surveys, Jones and Thompson surveys were equally adequate in distinguishing between different sites. The combining of data collected by several Jones and Thompson observers would increase accuracy by decreasing observer bias. However, the increase in man-hours of effort would have to be considered.

A representative Brock survey can be conducted in more than one habitat if the transect line is set where the substratum is representative of the species and proportions of coral and algae present in the general area. However, as discussed on page 7, if a Jones and Thompson survey was conducted in more than one habitat, the time interval numbers assigned to species would be dependent on the time interval when the observer swam over the particular substratum type characteristically inhabited by those species regardless of their actual abundances. The Jones and Thompson observer must take care to avoid swimming through more than one habitat per survey.

Due to time constraints, we were not able to test a modification of the Jones and Thompson method which we propose for use in areas with more than one habitat type, such as a reef extending from shore to a depth of 20 meters. Rather than assigning a single time interval number to each species, the observer would record every species seen in each time interval. The underwater survey sheet would be arranged with columns for time intervals and rows for species names. The observer would simply place a checkmark next to the species name in the column corresponding to the appropriate time interval. During transcription of the data after the dive, the number of checkmarks recorded for each species would be totalled. An indication of the relative abundance of species in an area with different substrata would be obtained. Without the modification described here, it would be necessary to conduct a separate survey in each habitat and data regarding the relative abundance of species from different habitats would not be available.

This modification requires that the number of time intervals which the observer spends in each habitat be proportional to the frequency of occurrence of that habitat relative to other habitats in the area under study. The observer would need to distinguish between different habitats but would not need to restrict observation to one habitat.

Both the Brock method and the Jones and Thompson method are valid visual survey techniques. When an area is under intensive study and replicable surveys are essential, the Brock method should be used. In cases where absolute abundances are required or where the length of each individual fish must be noted to obtain biomass approximations, the Brock method must be used. When available field time is minimal and the main objective is to characterize fish communities so that sites can be distinguished and compared on that basis, the Jones and Thompson method is more cost-effective. The Jones and Thompson method would also be preferred when bottom time is a critically limiting factor or when conditions of strong current, heavy surge, or extreme vertical relief prohibit the setting of a transect line.

PROCEDURE FOR CONDUCTING OF FISH SURVEYS
AT HANAUMA BAY

OBSERVER TEAM A CONDUCTED		OBSERVER TEAM B CONDUCTED
1. Jones and Thompson on Line 1	while	Brock on Line 2
2. Brock on Line 1	while	Jones and Thompson on Line 2
3. Brock on Line 2	while	Jones and Thompson on Line 1
4. Jones and Thompson on Line 2	while	Brock on Line 1
5. 1 through 4 (repeated)	while	1 through 4 (repeated)

Table 1. During the fieldwork at Hanauma Bay, each observer team performed both the Brock and the Jones and Thompson methods on each of the two lines and repeated this procedure for a total of eight surveys per team per day.

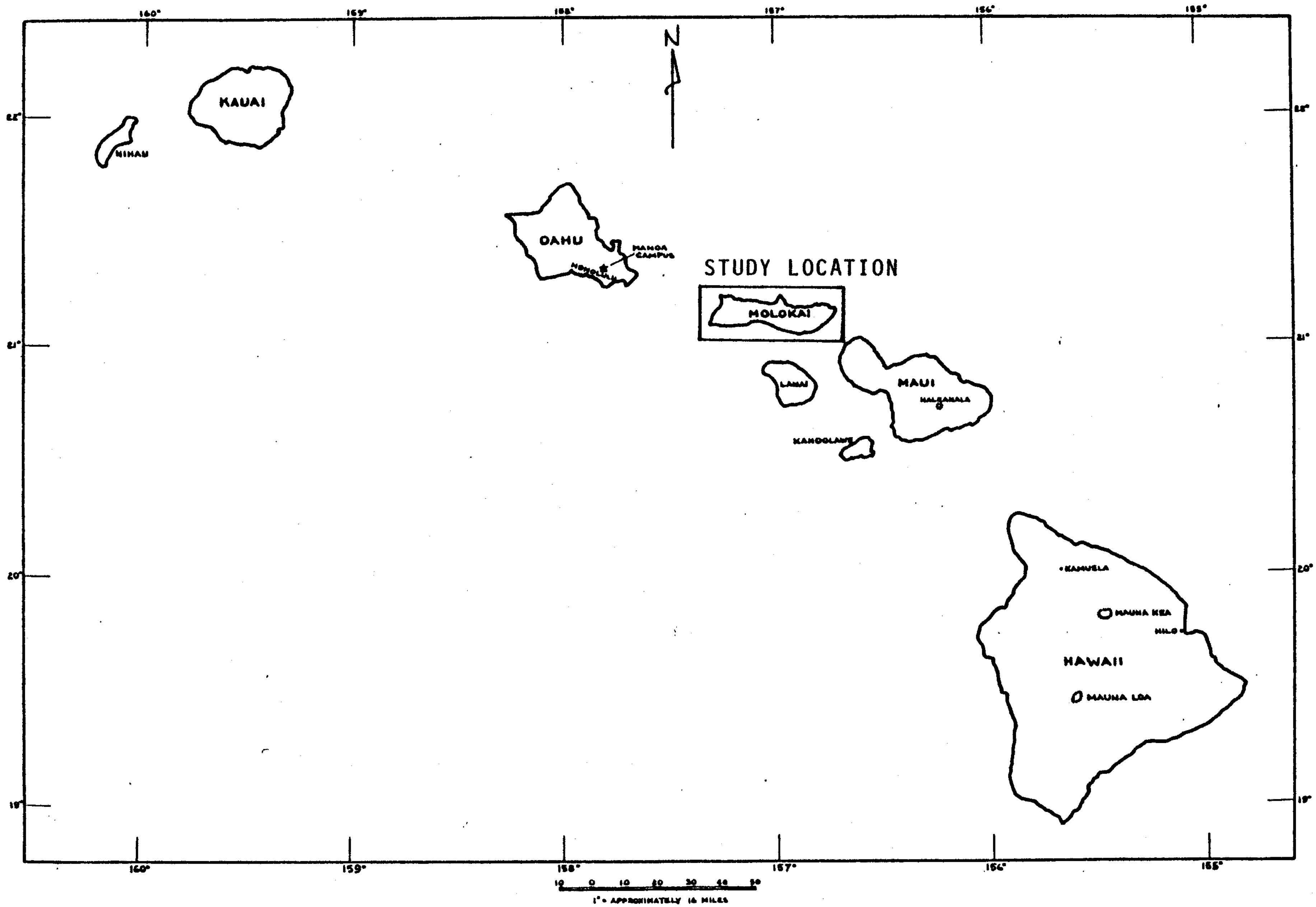

Figure 1. Map of the Hawaiian Islands, showing Molokai as the study location.

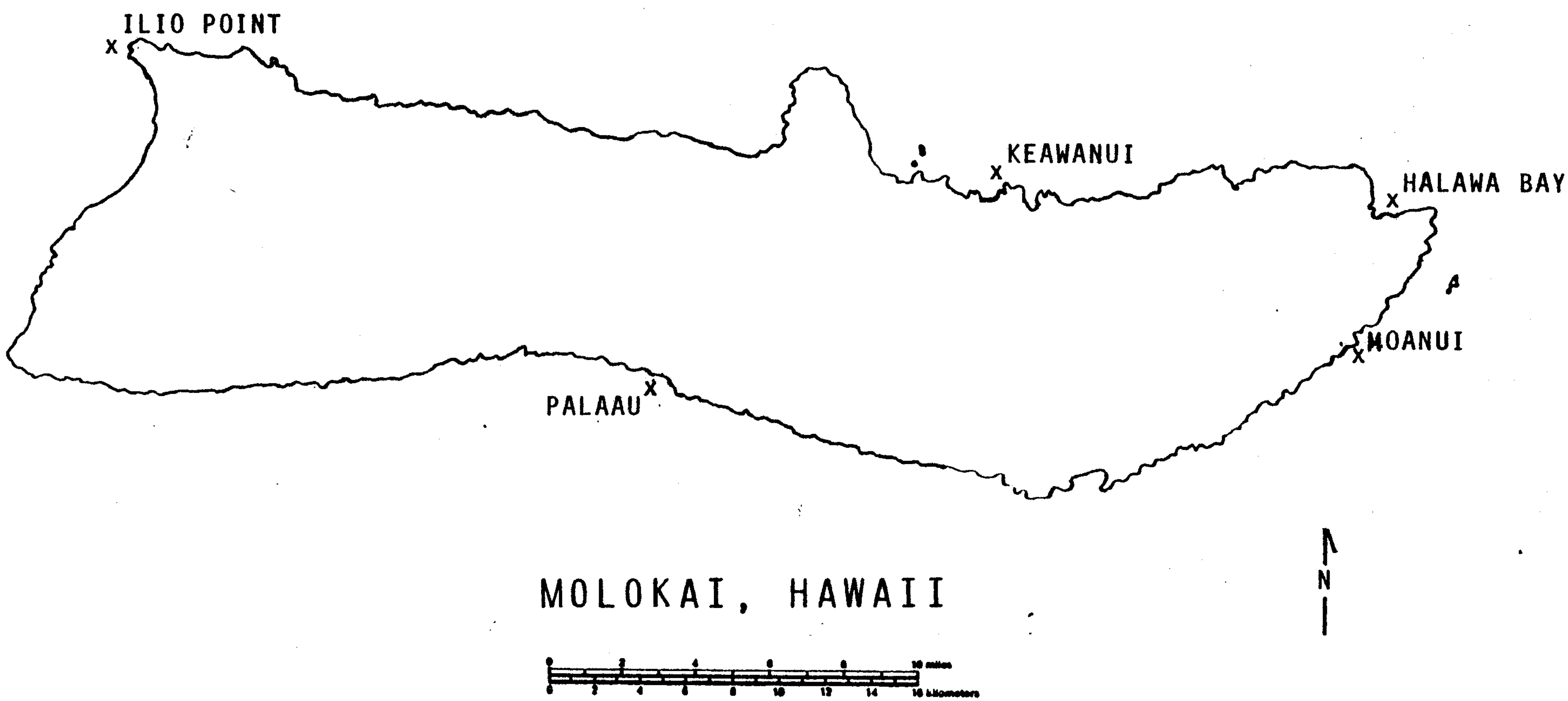

Figure 2. The five survey areas off the island of Molokai.